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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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PHYSICAL METALLURGY DIVISION

INTERNAL REPORT PM-M-73-9

# ALUMINUM-TIN ALLOYS PRODUCED BY POWDER METALLURGY

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Nuclear and Powder Metallurgy Section

April 2, 1973

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## ABSTRACT

Aluminum-tin powder metallurgy alloys containing 20 to 40% Sn and 0 to 3% Cu were prepared by compaction and extrusion of prealloyed atomized powder. The powder metallurgy (P/M) material had a fine distribution of the tin phase and was stronger, with greater fatigue strength, but harder and less ductile than an Al-20% Sn-1% Cu cast alloy. Heat treatment lowered the hardness of the P/M alloys to values comparable to those of the cast material, while the strength, although also reduced, remained superior to that of the cast product.

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* Physical Scientist and ** Research Scientist, Nuclear and Powder Metallurgy Section, Physical Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

## INTRODUCTION

Aluminum alloys containing 20 and 30% Sn with 1 and 3% Cu are attractive for use as bearing materials to replace white metal alloys (tin-base and lead-base) and are being used extensively in the automotive industry as liners for main and connecting rod bearings [1-5]. These alloys have good wear resistance and high load-carrying capacity, fatigue strength, and thermal conductivity. They also have excellent corrosion resistance in lubricating oils. Full advantage of the Al-Sn alloys is obtained by bonding them to a steel backing [6-9].

A problem in casting aluminum-tin alloys is that a deterioration in mechanical properties occurs when the tin content is increased above 10%. Tin has a negligible solid solubility in aluminum and there is a wide difference in the melting temperatures of the two metals, so that on solidification a pure tin phase envelopes the aluminum grains. To break up this continuous network of tin and produce what is referred to as "reticular" structure, it is necessary to cold work and anneal the cast structure of high-tin alloys.

An alternate method of producing aluminum high-tin alloys with a finely dispersed tin phase is by powder metallurgy (P/M) techniques using pre-alloyed atomized powder. Rapid solidification of the liquid droplets during atomization should result in a fine distribution of the tin phase. This work examines the feasibility of producing aluminum-tin bearing alloys by the P/M route. Tensile, fatigue and hardness tests are used to compare the P/M alloys with the cast material.

## EXPERIMENTAL PROCEDURE

The pre-alloyed powders listed in Table 1 were prepared by alloying aluminum (99.9% purity), tin (99.9% purity), and copper (OFHC) in a silicon carbide crucible coated with china clay and heated in an electrical resistance furnace. Each melt (1800g) was treated with a chlorinated hydrocarbon de-gassing tablet, skimmed and poured into an apparatus in which the molten alloy was atomized by jets of compressed air. The powder was collected in water and immediately washed in methyl alcohol to minimize any reaction with the water. All powders were then air dried.

TABLE I. Alloy Powder Composition, Wt %

| Nominal Composition | Chemical Analysis | | |
|---|---|---|---|
| | Sn | Cu | Al |
| Al-20% Sn | 20.67 | - | Remainder |
| Al-20% Sn-1% Cu | 19.34 | 1.00 | Remainder |
| Al-20% Sn-3% Cu | 19.80 | 3.00 | Remainder |
| Al-30% Sn | 28.61 | - | Remainder |
| Al-30% Sn-1% Cu | 29.24 | 0.78 | Remainder |
| Al-30% Sn-3% Cu | 29.20 | 2.95 | Remainder |
| Al-40% Sn | 39.19 | - | Remainder |

The minus 149 micron (100-mesh) fraction was screened from the powders and isostatically cold pressed at 10 ksi (69 $MN/m^2$) into billets 3.2 cm in diameter by 6.4 cm long, then unidirectionally hot pressed at 200°C (390°F) and 23.5 ksi (162 $Mn/m^2$) for 5 min. Al-20% Sn and Al-20% Sn-1% Cu hot-pressed billets were cooled to 130°C (265°F) and extruded into 1.3-cm-diameter rod. To prevent the formation of cracks, it was found necessary to jacket the other alloys in aluminum before extruding at this temperature.

To determine the effect of heat treatment on the mechanical properties of the extruded alloys, specimens were heat treated in air at 150°C (300°F), 225°C (435°F), and 350°C (660°F).

For comparison with the P/M alloys, Al-20% Sn-1% Cu and Al-20% Sn-3% Cu compositions were made as chill castings (15.2 cm x 8.9 cm x 1.3 cm) which were given 20% cold work by rolling and then annealed at 350°C (660°F) for 1 hr to produce a reticular structure.

Specimens for microexamination were rough polished on silicon carbide abrasive paper to a 600 grit then with 9-, 3-, and 1/2 - micron diamond paste on Metron B cloth.

Mechanical tests were carried out on the alloys in the conditions indicated in Table II. Tensile specimens were 3.8 cm long with a 1.6-cm gauge-length and a 0.4-cm gauge-diameter. Compression specimens were right cylinders, 1 cm in diameter by 1.3 cm long. The fatigue specimens, which were tested on a Krouse High-Speed rotating beam machine, had a 0.5-cm gauge-diameter and were tested for $5 \times 10^7$ cycles.

## RESULTS AND DISCUSSION

### Microstructure

The microstructure of Al-Sn P/M alloys is difficult to resolve using either optical microscopy or electron microscopy with replica. However, an electron-scan micrograph of the Al-30% Sn-1% Cu P/M alloy, Figure 1, shows a fine distribution of the tin (white areas). X-ray distribution images taken on the scanning electron microscope also showed the tin to be distributed as indicated in Figure 1. This structure is typical of the other P/M alloys; the addition of copper had no visible effect on the microstructure.

TABLE II. Properties of Alloys

| Alloy | Condition | Tensile | | | Compression ksi ($MN/m^2$) | | VHN 5 Kg Load | Fatique psi ($MN/m^2$) $5 \times 10^7$ Cycles |
|---|---|---|---|---|---|---|---|---|
| | | UTS ksi ($MN/m^2$) | 0.2% Y.S. ksi ($MN/m^2$) | % El $4\sqrt{Area}$ | U.C.S. | 0.2% Y.S. | | |
| Al-20 Sn | As-Extruded | 28.3 (195) | 26.6 (183) | 5 | N.D. | 26.8 (185) | 57 | 6,000 (41) |
| Al-20% Sn-1% Cu | As-Extruded | 32.8 (226) | 30.0 (207) | 5 | 42.0 (290) | 29.2 (201) | 73 | 10,000 (69) |
| Al-20% Sn-1% Cu | Extruded - (a) Annealed | 25.3 (159) | 24.7 (170) | 4 | 32.4 (224) | 26.7 (184) | 35 | 6,000 (41) |
| Al-20% Sn-3% Cu | As-Extruded | 45.5 (314) | 43.5 (300) | 3 | 57.5 (396) | 39.8 (274) | 84 | 12,000 (83) |
| Al-30% Sn | As-Extruded | 27.5 (190) | 26.3 (181) | 3 | 42.8 (295) | 27.7 (191) | 58 | 6,000 (41) |
| Al-30% Sn-1% Cu | As-Extruded | 35.3 (244) | 34.5 (238) | 1 | 43.2 (298) | 33.8 (233) | 78 | 8,000 (55) |
| Al-30% Sn-1% Cu | Extruded - (b) Annealed | 29.5 (204) | 27.1 (187) | 2 | 37.6 (259) | 30.0 (207) | 47 | 10,000 (69) |
| Al-30% Sn-3% Cu | As-Extruded | 40.6 (280) | 38.8 (268) | 2 | 52.1 (359) | 35.6 (246) | 83 | 10,000 (69) |
| Al-40% Sn | As-Extruded | 25.7 (178) | N.D. | N.D. | 35.5 (245) | 26.1 (180) | 53 | 7,000 (48) |
| Al-20% Sn-1% Cu | Cast - (c) Reticulated | 16.4 (113) | 8.7 (60) | 26 | N.D. | 9.6 (66) | 37 | < 2,000 (< 14) |
| Al-20% Sn-3% Cu | Cast - (c) Reticulated | 18.1 (125) | 10.0 (69) | 12 | N.D. | 11.3 (78) | 42 | < 2,000 (< 14) |

(a) Annealed 350°C (660°F) 1/2 Hr.

(b) Annealed 225°C (435°F) 1 Hr.

(c) Cold Rolled 20%, Annealed 350°C (660°F) 1 Hr.

N.D. Not Determined.

The distribution of tin in the as-cast and reticular structures of the Al-20% Sn-1% Cu alloy is shown in Figures 2 and 3, respectively.

Mechanical Properties

Mechanical properties of the extruded and heat-treated P/M alloys and of the cast material are listed in Table II. It is evident that all the as-extruded alloys have tensile, compression, and fatigue strengths superior to those of the cast alloys but are harder and have lower ductility. Some of the strength and hardness of the extruded alloys is presumably due to residual cold work after extruding at 130°C (265°F).

Effect of Heat Treatment on Mechanical Properties

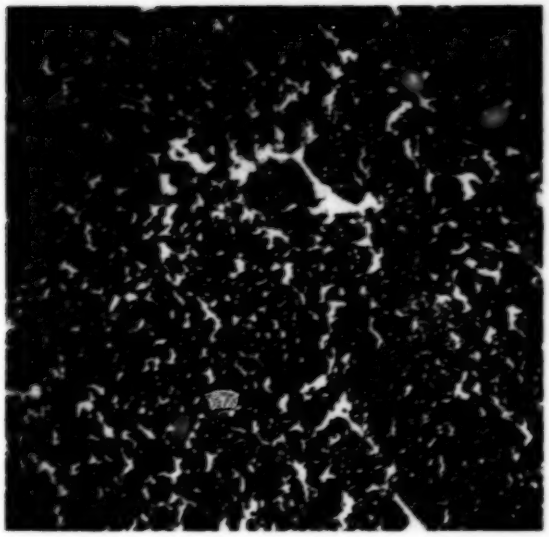
The effect of heat treatment on the hardness of the P/M alloys is shown in Tables III and IV. The data in Table III show that annealing at 225°C (435°F) and 350°C (660°F) reduces the hardness of the extruded material to values more acceptable for bearing alloys. Annealing the Al-20% Sn-1% Cu alloy for example, produces Vickers Hardness Numbers (VHN) from 33 to 42, which are comparable with that of the cast alloy of the same composition (VHN 37).

Heating at 150°C (300°F), which is about the maximum operating temperature for bearing alloys, for times up to 48 hr, produces some softening of all P/M alloys (Table IV). Table IV also shows that extended heating at 150°C (300°F) of the alloys annealed at 225°C (435°F) produces a slight softening of Al-30% Sn-1% Cu and Al-30% Sn-3% Cu alloys but has little effect on the others.

Table II shows that the ultimate tensile strength of the Al-20% Sn-1% Cu P/M alloy is reduced after annealing at 350°C (660°F) for 1/2 hr but is still superior to that of the Al-20% Sn-1% Cu cast alloy (24.7 ksi, 170 $MN/m^2$ and 16.4 ksi, 113 $MN/m^2$ respectively). Also, the compressive yield strength and fatigue strength of the annealed P/M alloy are about three times those of the cast product.

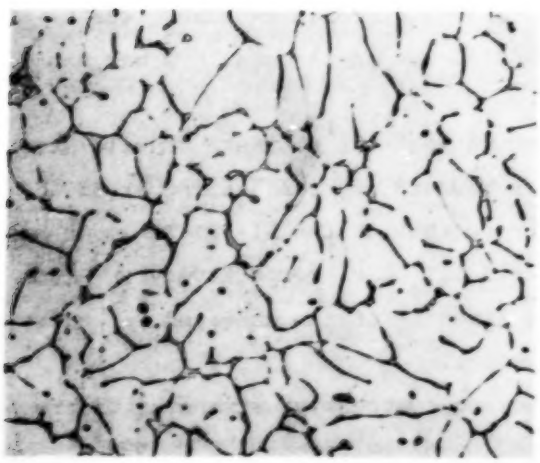
The tensile and compressive strengths of the Al-30% Sn-1% Cu P/M alloy are also reduced on annealing at 225°C (435°F) for 1 hr but again they are still superior to those of the cast alloy.

Values for the % El show that the decrease in hardness and strength on annealing does not result in a corresponding increase in ductility. The high-oxygen content (2.3% and 1.9% for Al-20% Sn-1% Cu and Al-30% Sn-1% Cu P/M alloys, respectively) is thought to be the cause of the low ductility.



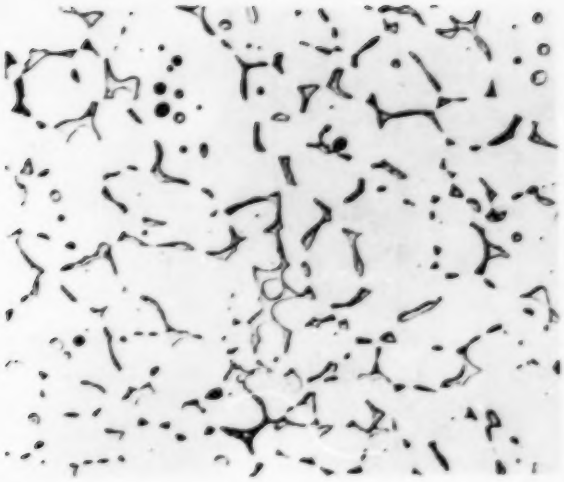
X1000

Fig. 1. Al-30% Sn-1% Cu P/M Alloy, Electron-Scan Micrograph.



X150

Fig. 2. Al-20% Sn-1% Cu, As Cast.



X150

Fig. 3. Al-20% Sn-1% Cu, Cast, Reticular Structure.
(Cold Worked 20%, Heat Treated 350°C (660°F) 1 hr).

TABLE III. VHN for P/M and Cast Alloys Annealed at 225°C (435°F) and 350°C (660°F) (5 Kg Load)

| Alloy | As-Extruded | 225°C (435°F) | | 350°C (660°F) | |
|---|---|---|---|---|---|
| | | 1 Hr | 2 Hr | 1/2 Hr | 1 Hr |
| Al-20% Sn | 57 | 32 | 31 | 26 | 26 |
| Al-20% Sn-1% Cu | 73 | 41 | 42 | 35 | 33 |
| Al-20% Sn-3% Cu | 84 | 47 | 45 | 30 | 30 |
| Al-30% Sn | 58 | 29 | 26 | 22 | 22 |
| Al-30% Sn-1% Cu | 78 | 47 | 50 | 27 | 28 |
| Al-30% Sn-3% Cu | 83 | 41 | 35 | 43 | 41 |
| Al-40% Sn | 53 | 31 | 34 | 25 | 24 |
| Al-20% Sn-1% Cu* | - | - | - | - | 37 |

* Cast alloy. Cold worked 20%, annealed 350°C (660°F) 1 hr.

TABLE IV. VHN of Extruded and Annealed P/M Alloys Heated at 150°C (300°F)
(5 Kg Load)

| Alloy | As-Extruded | Extruded and Annealed * | Time at 150°C (300°F) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 Hr | 2 Hr | 4 Hr | 8 Hr | 24 Hr | 48 Hr |
| Al-20% Sn | 57 | | 55 | 54 | 54 | 54 | 52 | 52 |
| Al-20% Sn | | 32 | - | - | 32 | 33 | 32 | 35 |
| Al-20% Sn-1% Cu | 73 | | 65 | 65 | 65 | 64 | 63 | 61 |
| Al-20% Sn-1% Cu | | 41 | - | - | 40 | 42 | 40 | 41 |
| Al-20% Sn-3% Cu | 84 | | 72 | 70 | 68 | 66 | 62 | 60 |
| Al-20% Sn-3% Cu | | 47 | - | - | 46 | 46 | 48 | 48 |
| Al-30% Sn | 58 | | 53 | 55 | 53 | 56 | 53 | 54 |
| Al-30% Sn | | 29 | - | - | 25 | 25 | 27 | 27 |
| Al-30% Sn-1% Cu | 78 | | 71 | 72 | 70 | 67 | 66 | 62 |
| Al-30% Sn-1% Cu | | 47 | - | - | 40 | 42 | 41 | - |
| Al-30% Sn-3% Cu | 83 | | 74 | 71 | 71 | 70 | 71 | 70 |
| Al-30% Sn-3% Cu | | 41 | - | - | 36 | 35 | 34 | 34 |
| Al-40% Sn | 53 | | 51 | 51 | 49 | 48 | 47 | 48 |
| Al-40% Sn | | 31 | - | - | 32 | 31 | 31 | 31 |

* Annealed 1 hr at 225°C (435°F)

## SUMMARY

1. Al-Sn (20-40% Sn) alloys with a fine dispersion of the tin phase can be produced by P/M techniques.
2. Extruded Al-Sn P/M alloys have greater tensile, compression, and fatigue strength than an Al-20% Sn-1% Cu cast bearing-alloy, but the P/M alloys are harder and have lower ductility.
3. Annealing of extruded Al-Sn P/M alloys reduces their hardness to values more suitable for bearing alloys and their tensile, compression and fatigue strength are still superior to the Al-Sn cast bearing-alloy.

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CFD:HMS:lm